On-axis Beam Accumulation Enabled by Phase Adjustment of a Double-frequency RF System for HEPS

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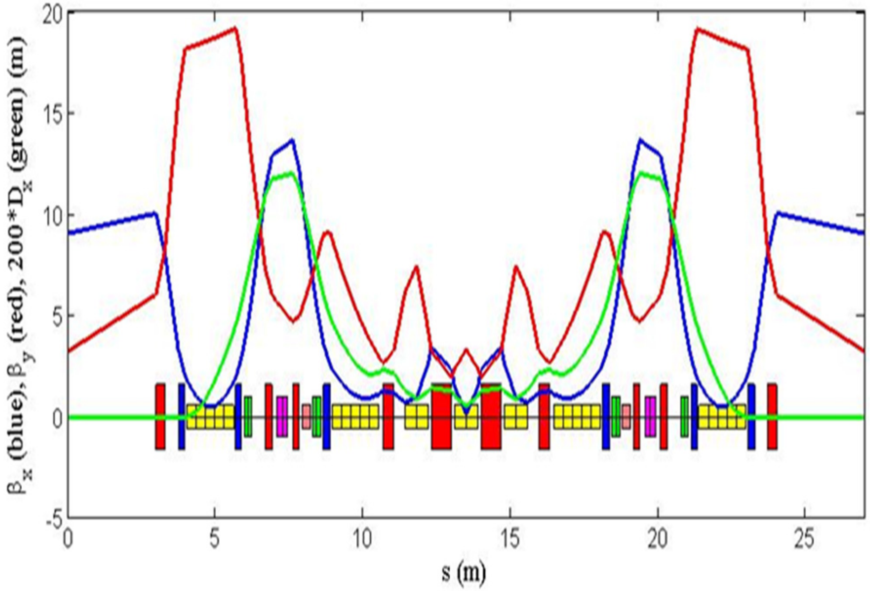
Topics

- Introduction to HEPS
- Different Injection schemes
- New scheme
- Comparison between different schemes
- Conclusion

High Energy Photon Source(HEPS)

Related studies on HEPS physics design, will be presented in WEPOW025, WEPOW026, HPMB019, THPMB017, THPMB018 in this conference.

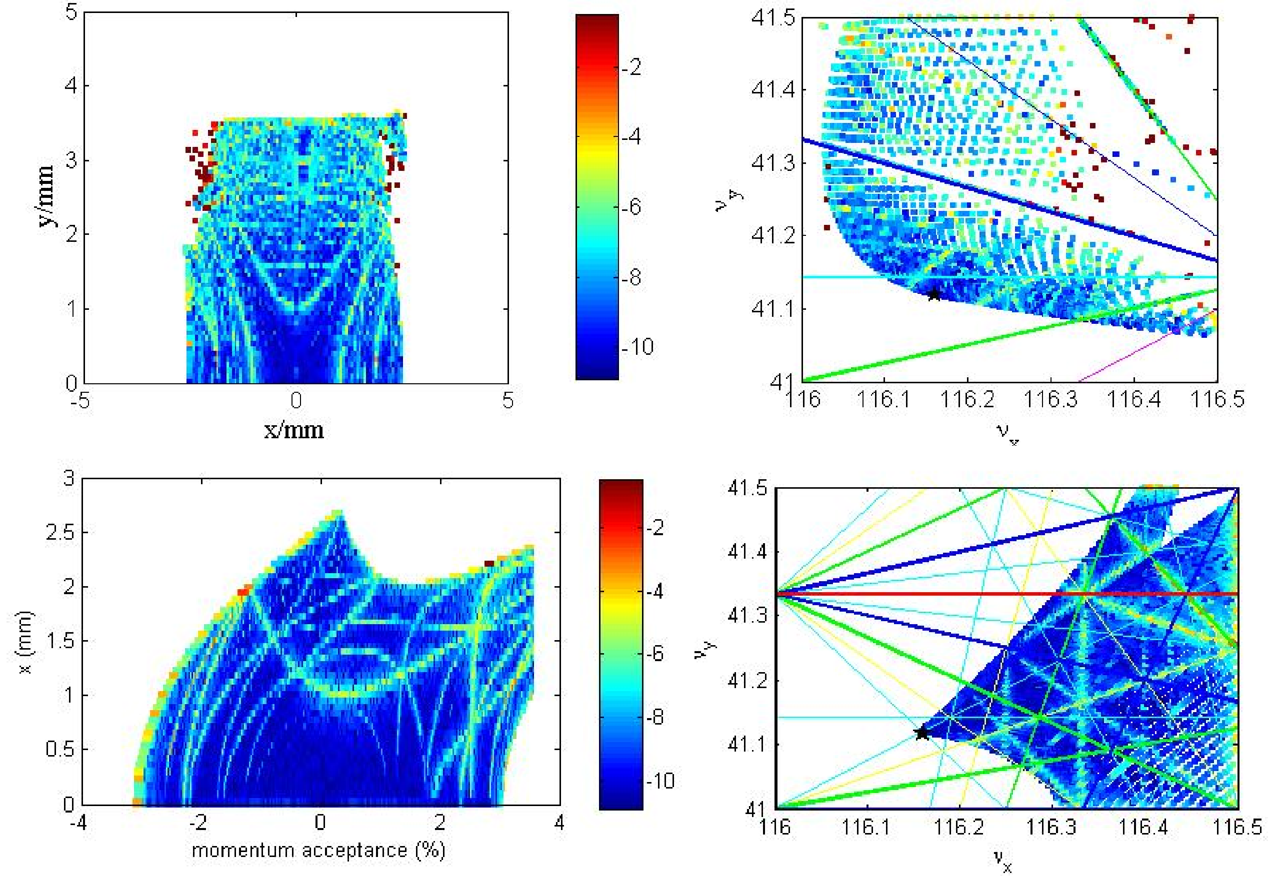


Optics function for one cell

Main parameters for HEPS

Parameter	Value
circumference C(m)	1295.616
beam energy E_b(GeV)	6
beam current I_0(mA)	200
natural emittance ϵ_0(pm)	59.4
betatron tunes ν_x/ν_y	116.155/41.172
momentum compaction α_c	3.74×10^{-5}
rms energy spread σ_ϵ	7.97×10^{-4}
harmonic number h_f/h_h	720/2160
SR energy loss U_0(MeV/turn) [2]	1.995
damping times(ms) $\tau_x/\tau_y/\tau_s$	18.97/25.99/15.95

HEPS lattice DA & MA



Different Injection schemes light source

- Transverse

  Orbit bump: need about 10~15mm DA, accumulation

  Nonlinear magnets: need 5mm DA at least , accumulation

  M. Borland, Swap-out: on-axis injection, 2~3mm DA , not accumulation

- Longitudinal

  Aiba(PSI), ”Golf club”, transverse kick, longitudinal accumulation

  Bocheng Jiang, double RF(250:500MHz), transverse kick, longitudinal accumulation

Our scheme

- fundamental(166.6MHz) + 3rd harmonic cavities(500MHz),(Other combination 100&300,or 216&650MHz is feasible, need some balance between RF and Kicker)
- Multiple cavities of each frequency(avoid Voltage fast ramping especially for SC cavities)
- Individually knob the reference phase of each cavities to fully utilize the four independent knobs, and a better control of RF buckets in longitudinal phase space
- First figure out important modes and then ramp RF phases, to obtain a complete injection cycle.

The longitudinal dynamics with a double-RF system

- A particle's longitudinal motion is described by the Hamiltonian

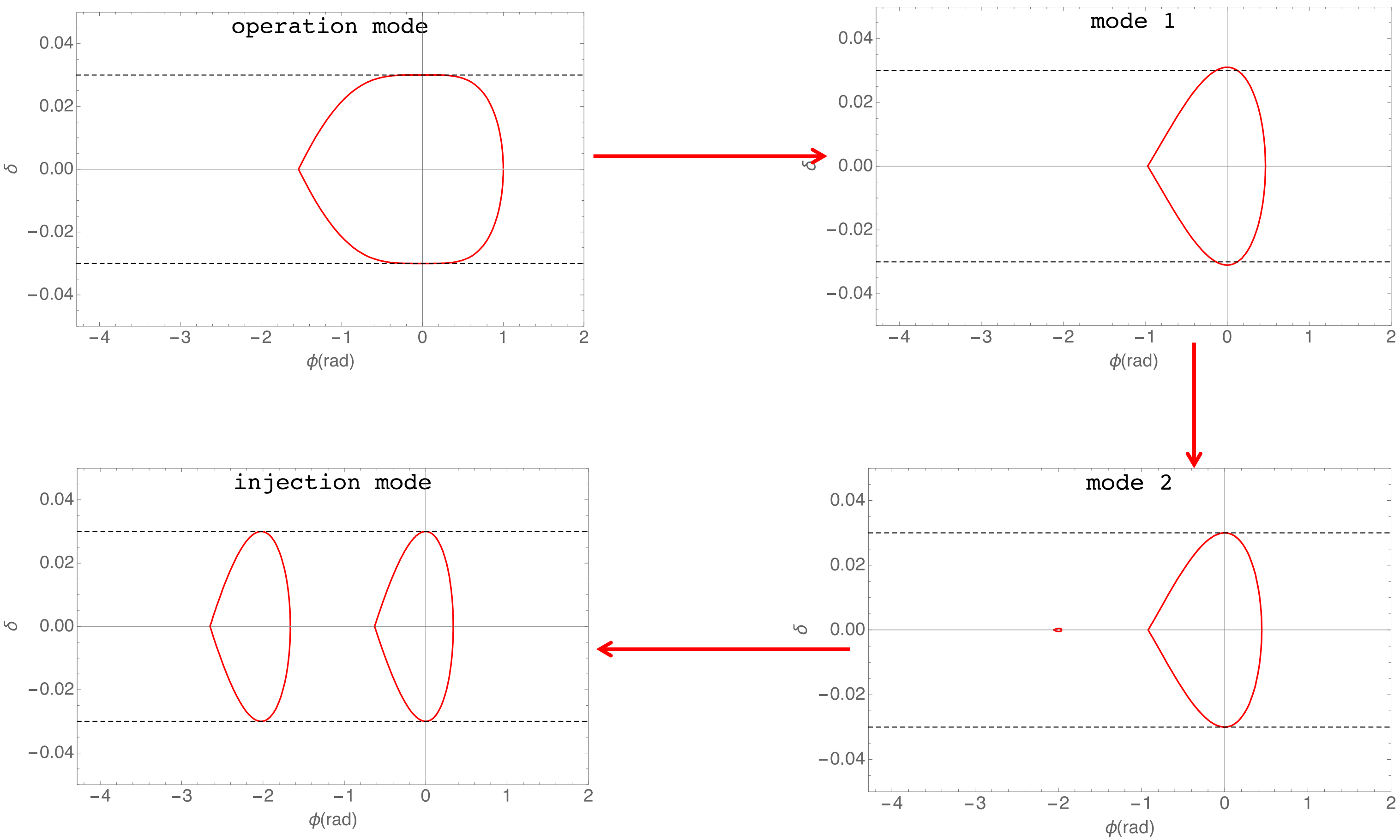
$$H(\phi,\delta;t) = \frac{h_f\omega_0\eta}{2}\delta^2 + \frac{\omega_0}{\pi E_b\beta^2}\left[\sum_{i=1}^{N_f} V_f^i \cos(\phi+\phi_f^i)\ \frac{h_f}{h_h}\sum_{j=1}^{N_h} V_h^j \cos(\frac{h_h}{h_f}*\phi+\phi_h^j) + \phi U_0\right]$$

- Equivalent RF voltages and phases:

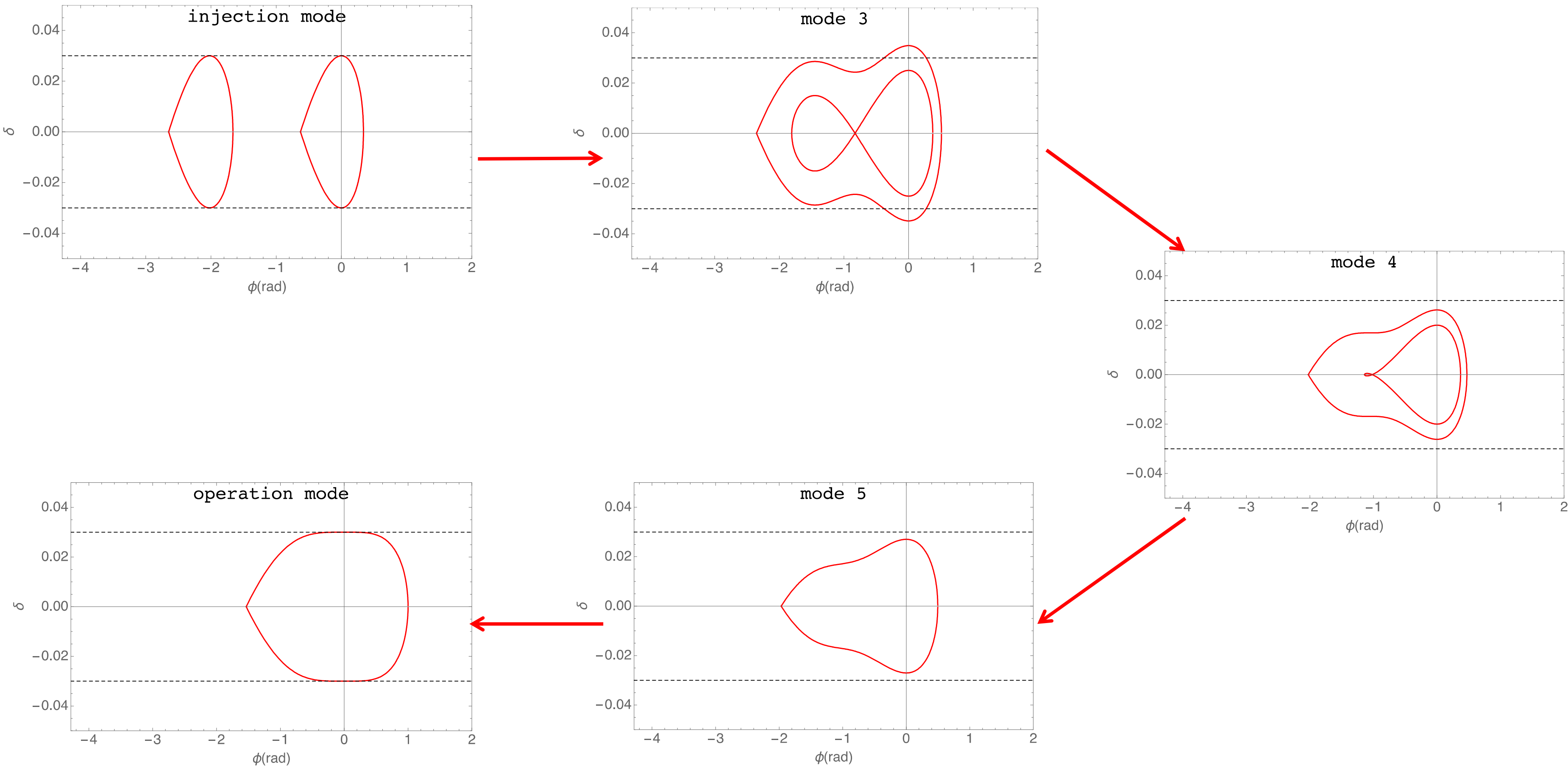
$$\begin{aligned} V_f\cos(\phi+\phi_f) &= \sum_{i=1}^{N_f} V_f^i\cos(\phi+\phi_f^i) \\ V_h\cos(\frac{h_h}{h_f}*\phi+\phi_h) &= \sum_{j=1}^{N_h} V_h^j \cos(\frac{h_h}{h_f}*\phi+\phi_h^j) \end{aligned}$$

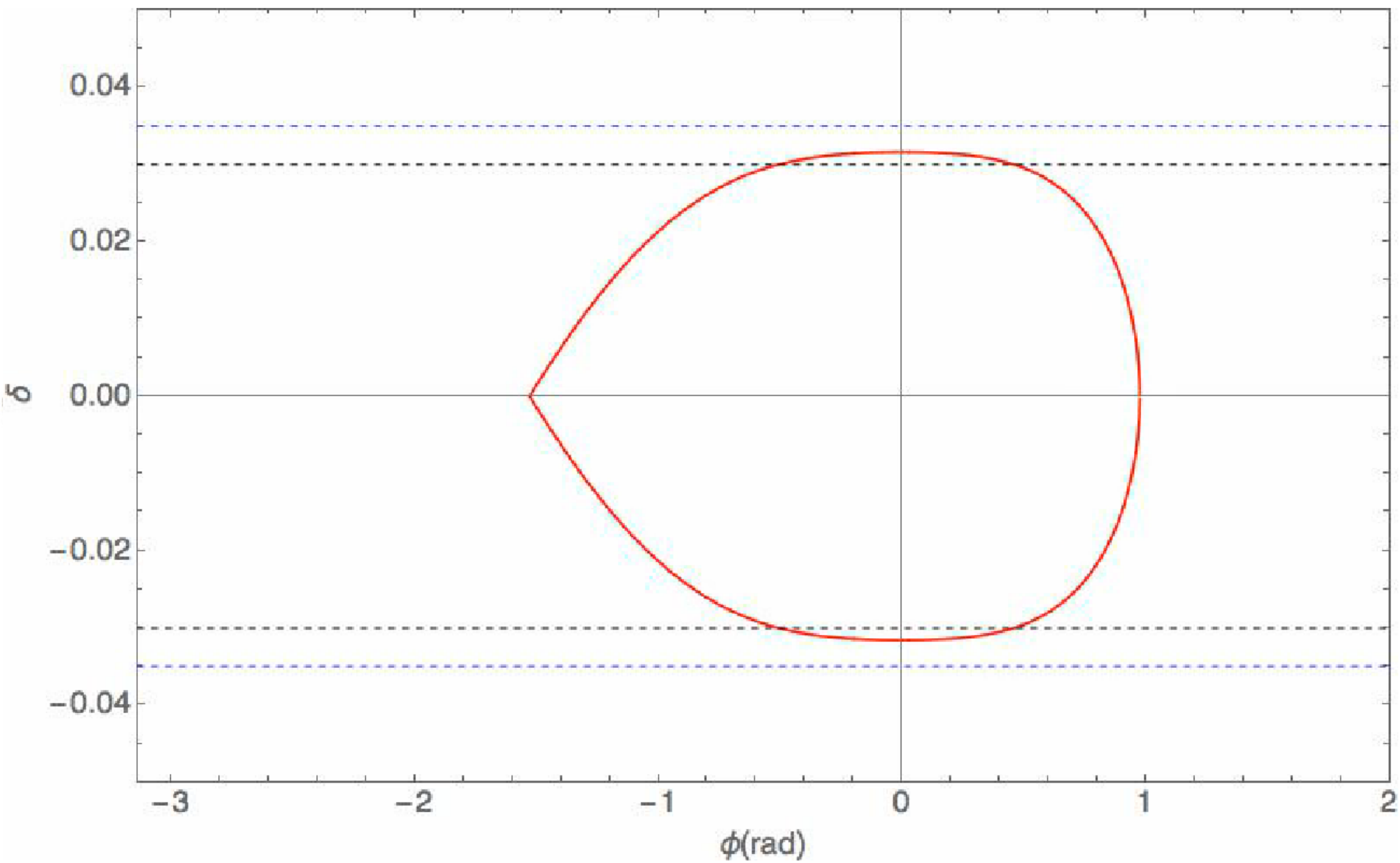
Four independent knobs (V_f, φ_f, V_h, φ_h)

Operation mode to injection mode

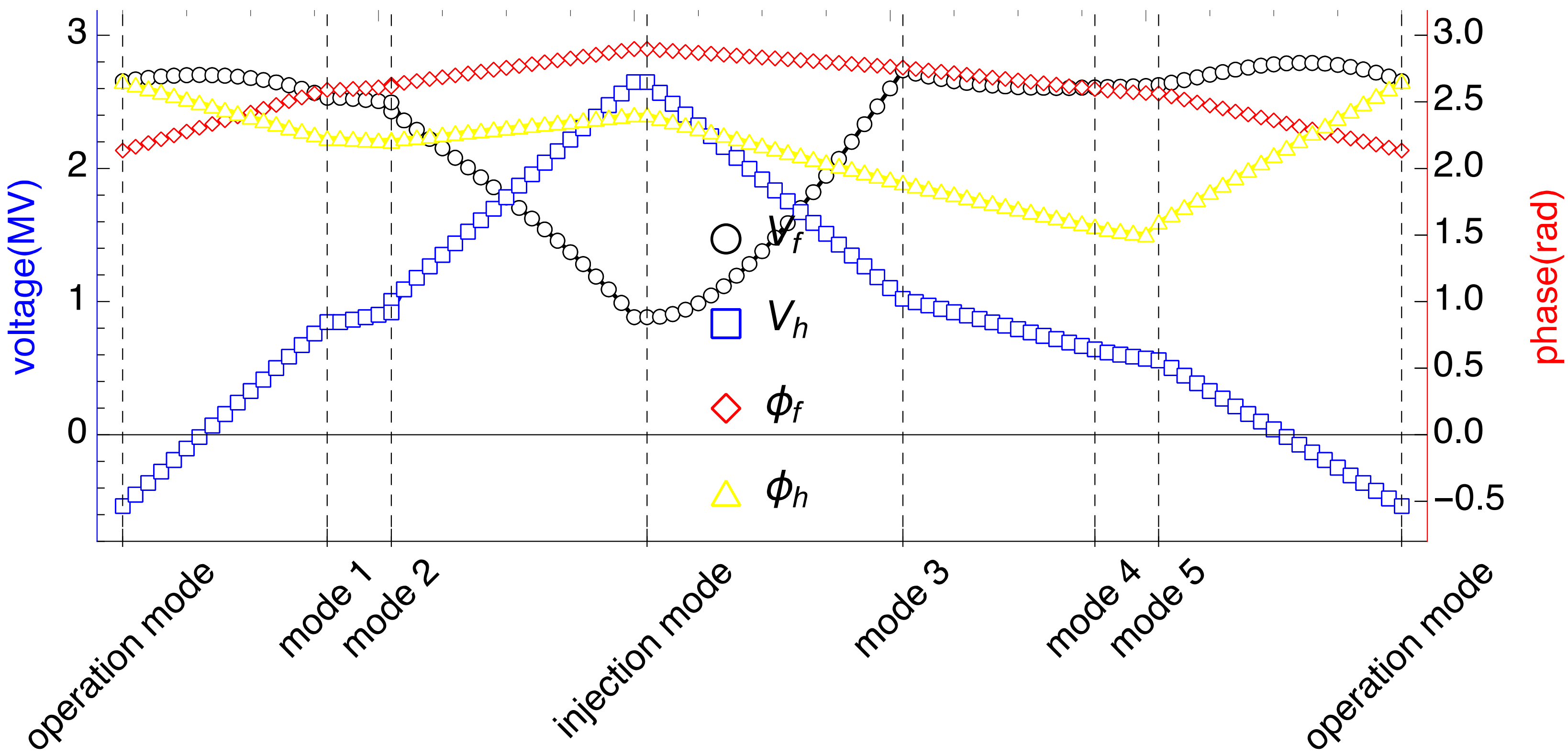


Injection mode to operation mode

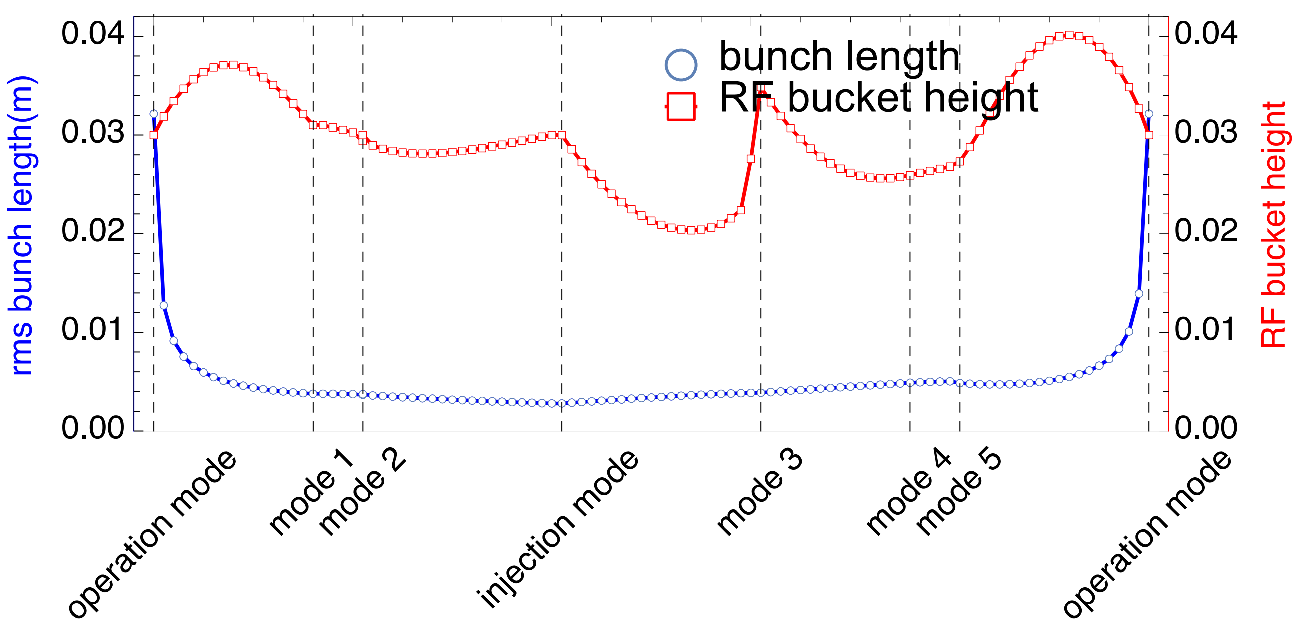



0.04
0.02
δ
0.00
−0.02
−0.04
−3
−2
−1
0
1
2
ϕ(rad)

Evolution of equivalent RF parameters



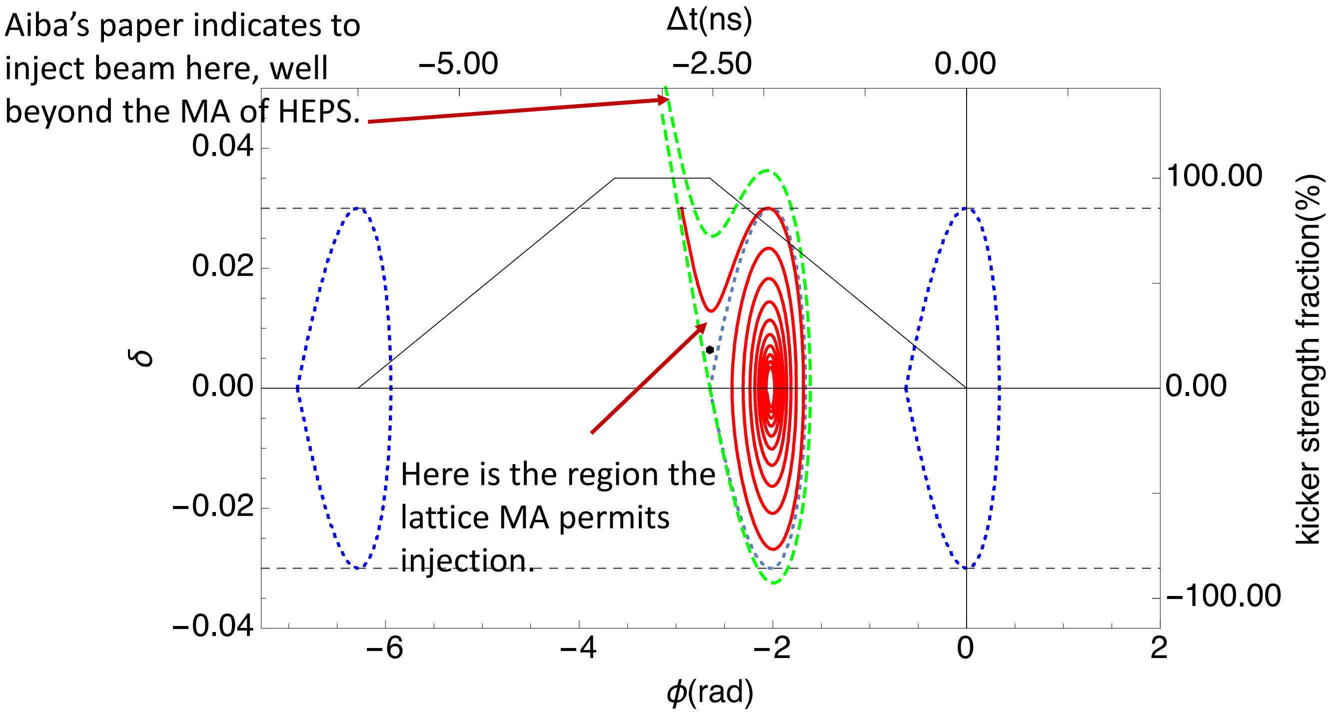
Evolution of circulating bunch parameters



Shortened bunch length leads to an emittance growth of about 10% assuming initial emittances are 60/10 pm, due to IBS.

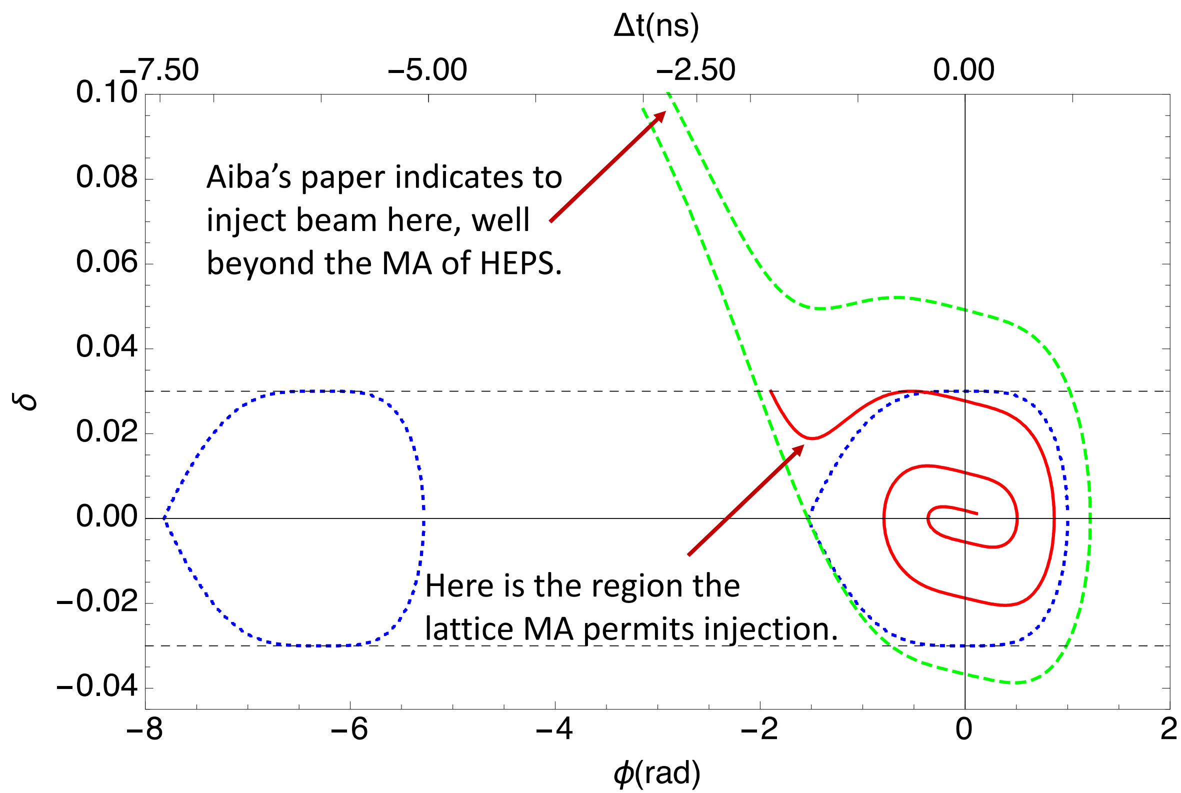
The beam lifetime also drops but an injection cycle takes several damping time and will not lead to observable beam loss.

Longitudinal phase space w/ radiation damping



Injection mode

Longitudinal phase space w/ radiation damping



Operation mode

Our scheme is superior in maximum allowed kicker rise time & tolerance of phase and energy jitter when applied at HEPS.

Comparison of different scheme

- Swap out: more beam intensity from injector, beam energy waste
- Golf club: need very large MA
- Jiang's scheme: center of circular beam vibrate by a large amplitude
- Our scheme: need additional active RF system, this is not so easy especially for the HOM issues of SC. 100/166MHz cavity.

Conclusion

- In order to overcome the shortage during injection for “old scheme” we propose a new scheme, it can avoid the beam/energy waste, the vibration of the center of circulation beam which is unlike for SR users, need not a very large MA. Of cause, it need a active 3rd harmonic RF system which means more money.

- Thank you very much for your attention!

Injection simulation(backup)

- Error seeds generation:
  - quadrupole relative gradient error of 5e-4 rms
  - quadrupole, sextupole and octupole roll error of 0.1mrad rms
  - horizontal and vertical misalignment error in sextupoles and octupoles of 25micron rms
- Select machines with beta-beating between 3% and 8%, vertical emittance between 5pm and 15pm. No correction is applied.
- 100 selected machines are used in injection tracking.
- Physical aperture: 11mm(Horizontal), 2.5mm(vertical, pessimistic)